Clinical applications

Brilliance iCT: initial experiences with the new generation of cardiovascular computed tomography systems

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MetroHealth Medical Center, located in Cleveland, is one of the largest healthcare providers in Northeast Ohio. MetroHealth is a leader in trauma, emergency and critical care, medical research and education, and is an affiliate of Case Western Reserve University School of Medicine. The Medical Center was the first hospital in the world to install the Philips Brilliance iCT scanner in October 2007. In this article, we present our early experiences in cardiovascular imaging with Brilliance iCT.

Background

Computed tomography angiography (CTA) has been widely adopted for most vascular applications. High-resolution, cross-sectional, isotropic images generated by multi-detector computed tomography (MDCT) scanners have been utilized successfully to image the vascular system. However, prior to recent enhancements in the speed, power and coverage of these MDCT scanners, challenges remained for the most demanding CTA application – imaging the coronary arteries.

The small caliber and rapid motion of the coronary arteries presents a significant technical challenge for CT scanners, which previously lacked the temporal resolution, spatial coverage and X-ray tube capacity to reproducibly image the coronary arteries at a broad range of heart rates and in a single breath hold.

The evolution of MDCT technology over the past decade from 2-slice to 64-slice configurations has addressed many of these challenges. Sub-second rotation times, isotropic sub-millimeter resolution and improved cardiac reconstruction algorithms have followed the trend of increasing slices. The combination of these enhancements has resulted in more consistent, higher-quality imaging of the coronary arteries. Clinical investigations using 16-, 40-, and 64-slice systems demonstrated the robustness and diagnostic accuracy of MDCT angiography (MDCTA) for the detection of coronary artery disease (CAD) [1-3], the increased mid-term prognostic value of MDCTA [4] and the positive impact of MDCTA on clinical decision making in the emergency room [5-8]. The combination of technological enhancements, and the body of scientific clinical proof, have thus established MDCTA as a viable non-invasive modality for coronary imaging.

Despite these advances – and the ability to image the majority of patients – there are still challenges in the performance of MDCT coronary imaging that need to be addressed. The temporal resolution and spatial coverage of 64-slice systems is still not sufficient to reliably image all of the fastest-moving coronary artery segments in all patients. As an example, obesity has been cited as an increasingly major health issue and is a significant independent risk factor for mortality from all causes, but especially from cardiovascular disease. However, imaging of the expanding bariatric and obese population with the limited X-ray output of 64-slice scanners...
Advances in MDCT technology enable high-quality imaging of the coronary arteries.

remains a challenge because of the limitation in the signal-to-noise ratio (SNR) necessary for reliable diagnosis. At the same time, reducing radiation dose without compromising image quality remains a priority and a challenge. Also, given that cardiac MDCTA exams are performed using ECG gating, more robust QRS detection, phase prediction and arrhythmia rejection remain as critical areas for enhancement in order to guarantee consistent, high-quality imaging in all patients at a variety of heart rates.

These opportunities for improvement have spurred a revolution in MDCT technology, culminating in the introduction of the Philips Brilliance iCT scanner at the 2007 meeting of the Radiological Society of North America (RSNA). This scanner is equipped with “Essence technology”, a collection of scalable enhancements to the X-ray tube, detector system and reconstruction engine (see Figure 1). The technical differentiators of the Brilliance iCT scanner include:

- Industry’s fastest rotation time of 0.27 sec, resulting in a standard temporal resolution of 135 msec
- Longitudinal coverage of 8 cm
- 120 kW tube and generator system providing high power for short-duration cardiac scans and larger patients
- Scalable Nano-Panel detector system reduces electronic noise, thus enabling high-quality imaging at reduced radiation dose
- RapidView image reconstruction system with Quad Core processors provides true cone-beam reconstruction for artifact-free, thin-slice imaging, while also improving temporal resolution via sophisticated adaptive multi-cycle reconstruction for optimized cardiac imaging
- Two-dimensional (2D) anti-scatter grid improves Hounsfield Unit (HU) uniformity, thus enhancing image quality over a larger z-axis coverage
- Dynamic Eclipse DoseRight collimator to significantly reduce radiation dose
- Smart Focal Spot system, doubling the number of samples and projections resulting in 256 slices
- Isotropic, sub-millimeter (0.67 mm x 0.67 mm x 0.67 mm) reconstructed voxel size
- Workflow improvements via an integrated ECG system with advanced QRS detection algorithm and robust arrhythmia handling mechanism.

In the following sections we discuss and present examples of early experiences with cardiovascular CT imaging using the Brilliance iCT scanner. All images shown are generated using the Comprehensive Cardiac Analysis application (CCA) on the CT workstation (Extended Brilliance Workspace).

Cardiovascular clinical applications

Retrospectively ECG-gated spiral coronary computed tomography angiography (CTA)

Using the Brilliance iCT scanner, we have noticed significant improvements in coronary artery imaging. The increase in volume coverage, the isotropic sub-millimeter resolution and the substantial improvement in temporal resolution make consistent, high-quality imaging of all coronary artery segments achievable. Using a
pitch of 0.14, the entire cardiac anatomy (12 cm) can be now covered in as little as five seconds. This has the additional benefit of facilitating a reduction in contrast agent volume compared to previous generation scanners.

Furthermore, the new integrated ECG acquisition system, advanced QRS detection algorithm and robust arrhythmia handling offer significant benefits. Optimum coronary imaging is enabled through the “Beat-to-Beat” variable delay algorithm that captures the same physiological quiescent phase [9-10]. R-tag editing is rarely necessary, given improved tracking of the R-tags along the QRS complex with ECG gating.

Temporal resolution is optimized, beyond what is enabled through the scanner hardware, by using an adaptive multi-cycle reconstruction algorithm that combines data from as many adjacent cardiac cycles as are present in the acquired data [11-12]; using this approach it is theoretically possible to achieve a temporal resolution between 36 and 135 msec. These technical improvements have substantially increased the chances of visualizing the entire coronary tree on a more consistent basis.

Figure 2 shows a clinical example of a coronary CTA scan acquired on the Brilliance iCT scanner. A 53-year-old male, with a history of chest pain, was referred for coronary CTA. The CT acquisition was performed using a volume of 80 cc of contrast (Optiray 350, Mallinkrodt) injected intravenously at a flow rate of 5 cc/sec. Automatic bolus tracking was used for optimal contrast enhancement. A region-of-interest was placed in the proximal descending aorta and scans were initiated six seconds after a pre-set threshold (150 HU) was reached. The average heart rate during the acquisition was 58 ± 5 BPM. An acquisition of 14 cm length was completed in six seconds. Though a small focal calcified plaque was observed in the proximal left anterior descending (LAD) artery, no significant CAD was found.

**Low-dose coronary computed tomography angiography (CTA): Step & Shoot Cardiac**

Various approaches exist to mitigate the risks of radiation exposure if the primary indication for a cardiac CTA exam is coronary artery assessment (e.g. if functional information is not needed). One such approach is Step & Shoot Cardiac, a prospectively ECG-gated sequential (axial) mode of scanning in which the X-rays are turned on only during a physiologically quiescent cardiac phase (e.g. ventricular diastasis), thus enabling a reduction in radiation dose of up to 80%.

Step & Shoot Cardiac uses a suite of proprietary algorithms to ensure consistent, high-quality coronary imaging. These algorithms include dedicated, true cone-beam reconstruction algorithms to reconstruct thin-slice 3D datasets for coronary evaluation. These advanced reconstruction algorithms prevent the artifacts that would appear if approximation algorithms were used to generate thin slice datasets. In addition, Step & Shoot Cardiac incorporates proprietary, advanced algorithms that accurately predict the arrival of the next cardiac cycle and

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**Figure 2.** Spiral retrospective gating on the Brilliance iCT.

**Figure 2a.** A three-dimensional (3D) angio-like view showing the coronary arteries. While the RCA is normal, a small focal calcified plaque can be seen in the proximal LAD.

**Figure 2b.** A volume-rendered image, with myocardium and the right chambers removed, demonstrates the sharp delineation of the coronary arteries.

**Figure 2c.** A maximum intensity projection (MIP) of the coronal view shows the course of the entire length of the RCA and LAD.
identify the quiescent cardiac phase. Robust, real-time arrhythmia handling available in the Brilliance iCT scanner serves to prevent unnecessary radiation dose to the patient by automatically turning off the X-rays upon the detection of a premature heartbeat, and until the heart rate stabilizes.

Figure 3 shows a clinical example of a coronary CTA performed using Step & Shoot Cardiac on the Brilliance iCT scanner. A 37-year-old female with shortness of breath and a family history of myocardial infarction was referred for a low dose Step & Shoot Cardiac coronary CTA scan. A total volume of 80 cc of contrast (Optiray 350, Mallinckrodt) was used with bolus timing as explained previously. The average heart rate during the scan was $55 \pm 4$ BPM and images were acquired over just two cardiac cycles. No significant CAD was found. The effective radiation dose was 4.3 mSv, well in line with average annual background radiation levels, and much lower than what would have been delivered using conventional spiral cardiac CTA.

**Tube power when needed: imaging obese patients**

Obese patients (e.g. patients with a body mass index [BMI] > 30 and/or weighing > 300 lbs) presenting with chest pain represent a challenge for assessment of underlying symptoms. Exercise stress testing is often not possible due to limited exercise capacity in these patients and standard imaging with echo or nuclear techniques is limited due to body habitus. In general, MDCT scanning in these patients is a challenge as the reduced SNR of the acquired images makes diagnosis difficult. With Brilliance iCT scanner’s significant increase in tube power (and thus superior SNR), compared to the existing generation of CT systems, we have been able to acquire high-quality scans in these patients. Shown in Figure 4 is a coronary CTA performed on the Brilliance iCT scanner of a morbidly obese female patient (BMI of 50) with a family history of CAD and a sub-optimal nuclear stress test. Using a total contrast volume of 90 cc (Optiray 350, Mallinckrodt) an acquisition length of 14 cm was covered in 5 seconds. The scan was of excellent quality, with no abnormal coronary findings. The average heart rate during the scan was $60 \pm 7$ BPM.

**Emerging applications**

The excellent speed, power and coverage available in the Brilliance iCT scanner, compared to the existing generation of CT systems, should enable users to see an expansion in their abilities to image cardiovascular diseases beginning today and extending well into the future.

At MetroHealth, we have observed an increase in incidental coronary findings in patients who have not yet been triaged. As an example, we performed a routine, non-gated chest CTA scan on a 76-year-old female patient suffering from melanoma. An acquisition length of 28 cm was covered in as little as 4 seconds with a reasonable radiation dose (8.6 mSv). Though this type of scan is not traditionally used to assess coronary arteries, and the contrast protocol was not optimized accordingly, the coverage and speed
of the scanner resulted in motion-free coronary artery images, thereby also enabling us to perform diagnostic coronary assessment with confidence. Figure 5 shows a coronal maximum intensity projection (MIP) of the right coronary artery (RCA) obtained from this non-gated chest CTA scan.

In addition to enhancing the use of MDCT in routine cardiac imaging, the synergistic combination of speed, power and coverage of the Brilliance iCT scanner should expand the use of MDCT into the frontiers of imaging and the forefront of cardiovascular care. This paradigm shift will encompass areas such as specific, focused assessments, expanded cardiovascular interventions and revolutionary analyses of global cardiovascular function.

Although MDCT has been used for valve and valve implant assessment, its role was limited by temporal resolution and coverage. The temporal resolution was insufficient to reproducibly image the valve leaflets and the smaller coverage required spiral acquisitions to cover the anatomy of interest, thereby preventing cine imaging. The wide coverage of the Brilliance iCT scanner makes it possible to perform focused valvular assessment and to study dynamic flow via cine imaging at a specific axial location. In addition, its fast speed allows the motion of the valve leaflets to be frozen. Similar techniques can be used to enable novel dynamic focused assessments requiring high temporal resolution and wider coverage, including dynamic stent assessment, dynamic coronary flow assessment, vascular compliance, aortic distensibility, compression of intra-myocardial coronary segments or anomalous congenital anatomy, and others.

Focused assessment can be extended beyond diagnosis, therapy planning and follow-up. The Brilliance iCT scanner may find expanded use in the cardiovascular interventional suite. For example, dynamic imaging and volume fluoroscopy [13] of the heart enables advanced treatment of electrophysiological diseases, such as atrial fibrillation and ventricular tachycardia, structural heart defects, such as patent foramen ovale (PFO), and atrial- and ventricular-septal defects, ischemic conditions and minimally invasive procedures.

In addition to the aforementioned focused assessments and interventions, the wider coverage and faster speed enable novel global assessments of cardiovascular function. While left ventricular function can be analyzed using the current generation of MDCT, the combination of coverage and speed of the Brilliance iCT scanner opens up new possibilities in anatomical and physiological assessment. Using a cine axial scan, capable of covering the entire left ventricle and myocardium, advanced analysis of functional parameters, mechanical stress and strain analyses – including true 4D inter- and intra-ventricular dyssynchrony and computational fluid dynamics (CFD) of the ventricle and vascular networks. Ultimately the advanced imaging capabilities of this machine will enable the transition from 4D morphological to 5D quantitative physiological imaging. More specifically, combining 4D anatomical information with myocardial contrast kinetics defines a path to true myocardial perfusion measurements. These true measurements will facilitate more accurate characterization of ischemic stunned, hibernating or infarcted myocardial tissue in the context of acute coronary syndromes (ACS), revascularization therapy and electrophysiological interventions.

Conclusion

With its increased speed, power and coverage the Brilliance iCT scanner provides improved imaging possibilities for use in cardiovascular diseases. It has paved the way to expand the application of cardiovascular MDCT to broader patient populations, providing consistent coronary image quality with reduced contrast and over a wider range of variable heart rates. Incorporating improved dose management, scanning and reconstruction methodologies, it has enabled the radiation dose of a coronary CTA exam to be brought down to average background radiation levels. While it is expected that the scope and applicability of cardiovascular MDCT will to continue to broaden to include areas such as whole-organ perfusion and other emerging applications, this scanner is also well positioned for use in existing, as well as emerging, neurovascular and body applications.
References


